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# POSM: A new concept for fiber positioning

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## ABSTRACT

The Gemini/Subaru WFMOS project has given the stimulus for considering new concepts for massively multiplexed fiber positioning schemes. The problem of acquiring many thousands of objects within a  $\sim 1.5^\circ$  field at Subaru's  $\sim f/2$  prime-focus station represents a challenge to normal concepts of fiber positioning. Solutions usually involve imposing limits to the patrol field of each fiber. Using this simplification, a new concept is proposed which moves objects onto a fixed array of fibers rather than moving the fiber themselves. Such a scheme may simplify the manufacturing and assembly processes and may result in a more robust solution compatible with the challenging prime-focus environment. We describe the POSM concept and present an initial opto-mechanical layout.

## 1. INTRODUCTION

We have witnessed over the past few years the need for a massively multiplexed spectroscopic instrument located on an 8m-class telescope to satisfy requirements for increasingly high profile science proposals such as the study of dark energy [1] and galactic archaeology [2]. To obtain the required AOMEGA product of the system to perform these surveys in a reasonable amount of time one traditionally adopts a prime focus location, with wide-field corrector, combined with a spectrograph capable of obtaining simultaneous spectra of several thousand objects over the field of the prime focus. If the spectrograph is divided into a prime focus fiber positioner feeding several fixed location spectrographs located off the telescope one can satisfy mass constraints imposed by adopting a prime focus location, whilst at the same time providing a stable environment, both gravitationally and thermally, for the spectrographs. This is the basis of the joint Gemini/Subaru WFMOS project for the Subaru telescope [3].

This paper proposes a new concept for a fiber positioner resulting from work directly associated with the WFMOS project, however, the positioner concept is applicable to other formats such as Nasmyth location with lower multiplex. Here we concentrate on the most difficult application, where the plate scale is sufficiently small ( $\sim 100\mu\text{m}/\text{arcsec}$ ) that robotic button placement devices such as 2dF [4] and OzPoz [5] cannot be applied. Only the revolutionary Echidna positioner [6] due for commissioning in late 2006 as part of the Subaru funded FMOS project [7] so far fulfils the WFMOS positioner requirements.

Here we ask, with the benefit of hindsight, how one would approach the design of such a positioner. When specifically applied to the WFMOS project we answered this question with the following approach:

- (1) Do not position with the optical fiber. Then one can mount all fibers in a single plate and polish like a mirror. This reduces the large labour cost associated with fiber polishing and individual mounting of the fibers in robotically controlled devices;
- (2) Be able to accept a non-pupil centric feed from the wide field corrector. This means that the wide field corrector can be optimized for an imaging application only, an important consideration if the corrector is to be used for both imaging and spectroscopy, as is the case with the WFMOS project;
- (3) Eliminate the need for a fiber connector. High numerical aperture fibers, required for the direct feed from the WFMOS wide field corrector, are expensive. Fiber connectors for astronomical applications are in general complicated, risky, with variable throughput loss from one to the next;
- (4) Have a fixed field per fiber. For this to be acceptable the target densities must be large compared to the number of fibers.

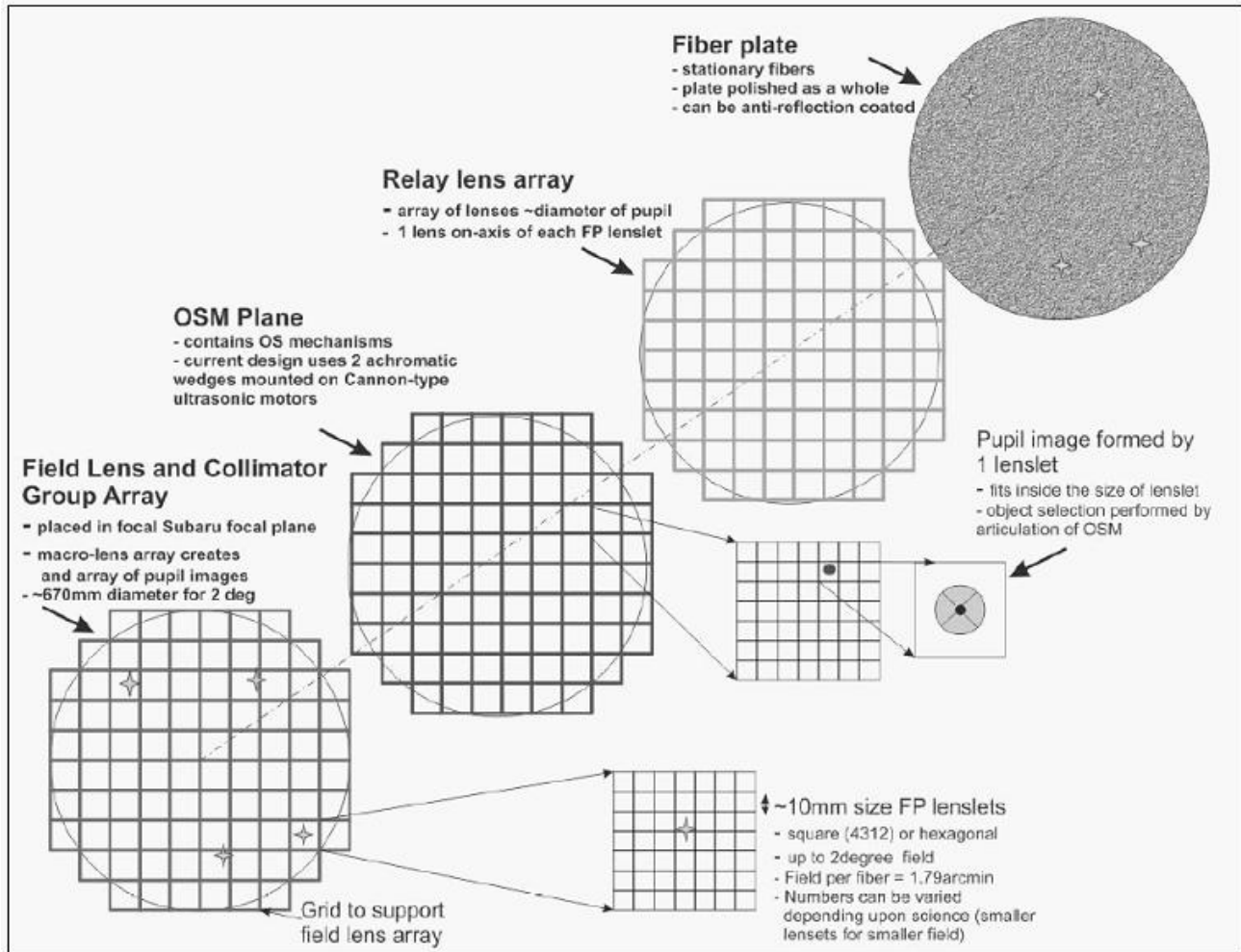
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## 1.1. POSM concept

A schematic of the proposed POSM concept is shown in Figure 1. The concept adopts a layered approach described as follows.

### 1.1.1. Fiber Plate

Shown far right in Figure 1, the optical fibers (some several thousand) are mounted and polished in a monolithic fiber plate. The idea is to cement the fibers in a fixed grid (shown as a square grid in Figure 1 that can be hexagonal for increased number density) in the plate that is then polished on a machine using a process identical to that of polishing an optic of an equivalent diameter (that is ~500mm for the WFMOs positioner). As the fibers are fixed in position the target beam must be steered into the optical fiber.



**Figure 1:** A schematic of the POSM concept. Instead of moving an optical fiber to a target the concept starts by mounting all optical fibers into a single fiber plate (far right).

### 1.1.2. Field Lens and Collimator Group (FLCG)

Shown far left in Figure 1 is the FLCG, a large macrolens array, which divides the focal plane into an array of small sub-fields. The purpose of the FLCG is to form a pupil image from every sub-field. The individual macrolens diameter is approximately 10mm corresponding to ~2arcmin sub-field size.

### 1.1.3. OSM plane

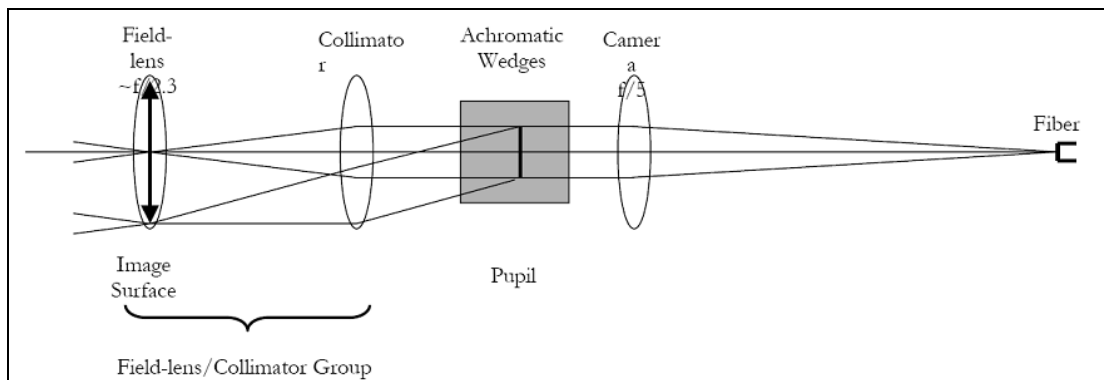
The plane of the Object Selection Mechanism (OSM) contains an array of identical beam steering mechanisms. The mechanism steers the target beam into the corresponding optical fiber for that field. This plane represents the location of the most complex part of the POSM positioner.

### 1.1.4. Relay lens array

Prior to the fiber plate is another macrolens array of camera lenses that focus the collimated light exiting the OSM plane to the optical fiber. There is one camera lens per sub-field.

## 2. POSM FLCG DESIGN

The Focal lens Collimator Group (FLCG) forms an image of the pupil from each of the several thousand sub-fields comprising the  $1.5^\circ$  focal plane of WFMOS. The fast input beam of the prime focus location and required focal length of the FLCG make the optical design a challenging venture. We present preliminary designs here.



**Figure 2:** A schematic of the POSM single channel. The Focal lens Collimator Group (FLCG) forms an image of the pupil from the sub-field corresponding to  $\sim 2$  arcmin diameter of the focal plane.

### 2.1. FLCG specifications for WFMOS

For the WFMOS positioner we require the following FLCG specifications:

- 9mm fiber pitch ( $\sim 2800$  fibers in total across a  $1.5^\circ$  diameter field)
  - $1.61'$  sub-field diameter (assuming  $F/2.34$  input from corrector)
- Hexagonal configuration
  - 10.44mm lens diameter
- Exit pupil diameter is  $0.5\text{--}0.3\times$  lens diameter
  - $0.5 \rightarrow 12.21\text{mm}$  focal length
  - $0.3 \rightarrow 8.14\text{mm}$  focal length
- Image quality
  - RMS spot size  $\sim 0.25\text{--}0.5$  arcsec ( $\sim 23\text{--}46$  micron  $F/2.34$ ,  $59\text{--}118$  micron  $F/6$ )
  - $400\text{nm}\text{--}900\text{nm}$  bandpass

For the FLCG we therefore require:

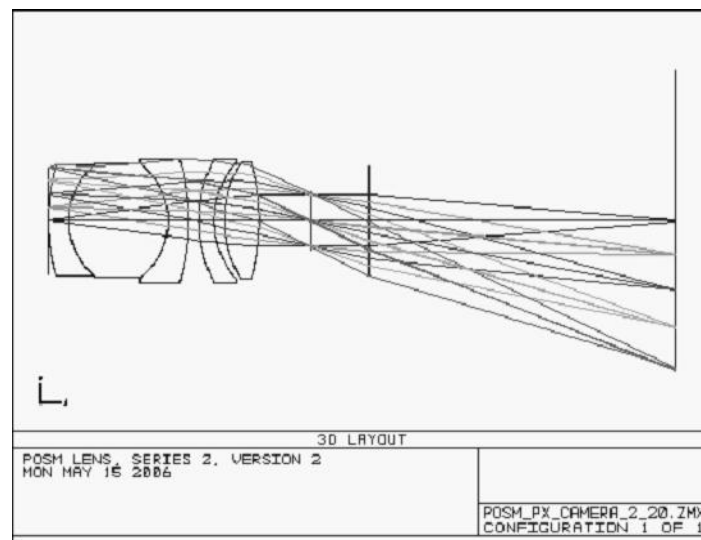
- A  $\sim f/1$  system or faster
- $\pm 30^\circ$  field of view for the collimator optics

## 2.2. Optical Designs

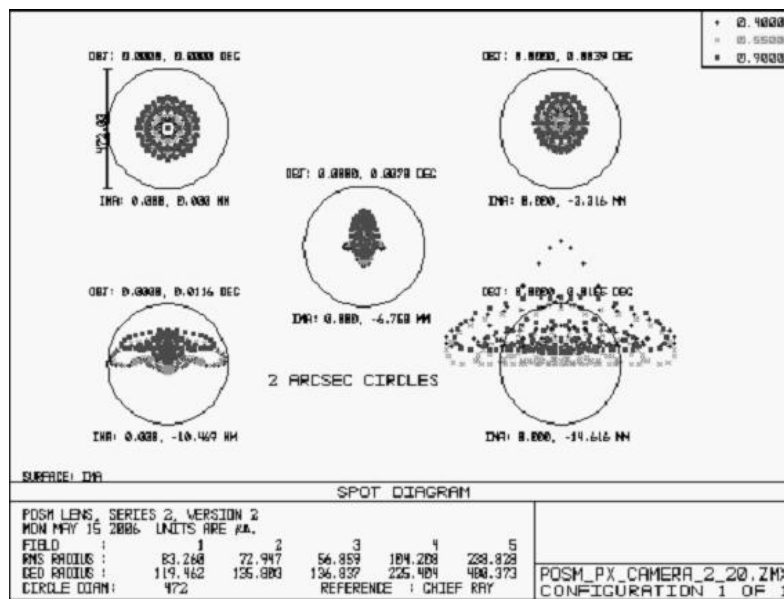
The FLCG is essentially an eyepiece in that it forms an image of the telescope pupil external to the lens group. There are deviations from the classical eyepiece requirements that can be summarized as follows: (1) the equivalent eye relief is smaller; (2) the exit pupil in theory can be non-collimated; (3) the field lens must be very close to focal plane to reduce gaps in the field and (4) none of the optics contained in a single channel can be larger in diameter than the sub-field diameter.

### 2.2.1. Wide field eyepiece design (1)

The Orthoscopic eyepiece shown in Figure 3 represents the best performance so far obtained for the FLCG providing a  $\sim F/6$  f/ratio input to the optical fiber. The eyepiece contains 5 lens elements with all spherical surfaces. The pupil diameter is  $\sim 0.45\times$  the size of the sub-field diameter. The orthoscopic wide field design has superior control of vignetting compared to other wide field eyepiece designs such as the Erfle.

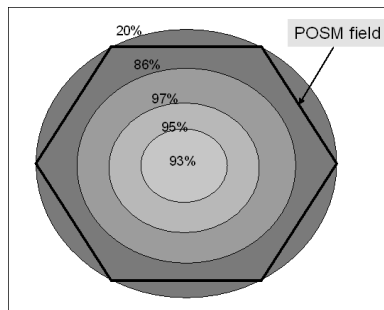


**Figure 3:** Optical layout of the wide field all-spherical Orthoscopic eyepiece design for the FLCG



**Figure 4:** Spot plots as a function of radius across the sub-field. The circles mark a 1arcsec diameter field.

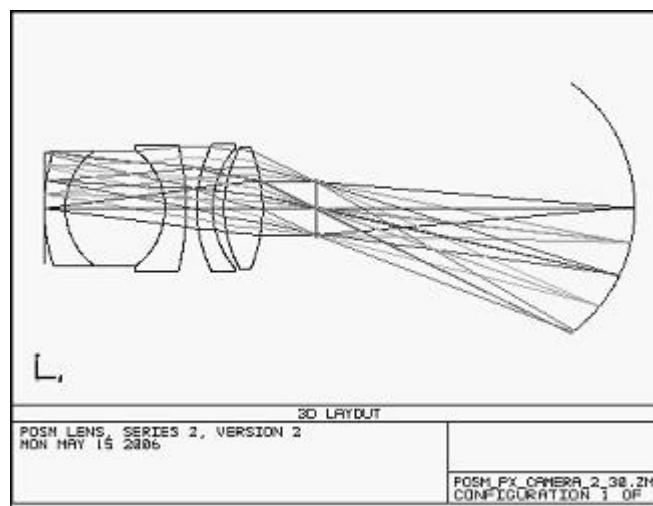
The image quality across the sub-field is shown in the spot plot diagrams of Figure 4. The circles mark a 1 arcsec diameter circle. The image quality starts to suffer towards the edge of the field only, that results in a direct coupling loss for a 1 arcsec diameter fiber core. Figure 5 summarizes the fiber coupling efficiency as a function of target position in the sub-field. The coupling efficiency starts to plummet at a radius of  $\sim 85\%$ .



**Figure 5:** Coupling efficiency into a 1 arcsec fiber for the wide field Orthoscopic eyepiece design

### 2.2.2. Wide field eyepiece design (2)

To improve the coupling performance we investigate a new avenue. As the majority of the image aberration experienced in the previous design comes from field curvature we allow a focus adjustment in each channel. This mechanism needs to be ultra-simple, discrete and provide relatively rough focus movement. The optical layout of this system allowing field curvature is shown in Figure 6.



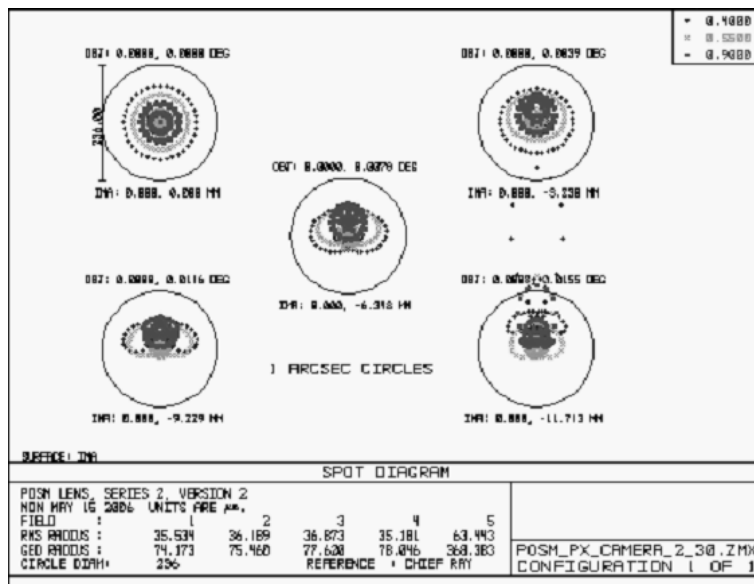
**Figure 6**

Allowing field curvature improves the performance instantly. The image quality rms diameter is  $\sim 0.3$  arcsec across most of field ( $\sim 0.6$  arcsec in blue at edge) as shown in Figure 7. Improved image quality at the field edge means much better coupling to 1 arcsec fiber, as shown in Figure 8.

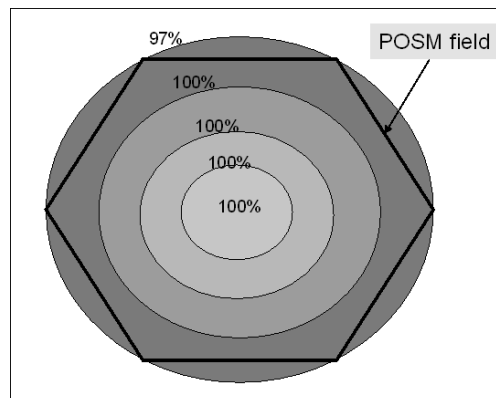
### 2.2.3. FLCG Conclusions

The Orthoscopic wide field design (2) serves as a good baseline design. We are working to improve on this design in the following ways:

- (1) Reduce pupil size
- (2) Conic/s to replace some air/glass surfaces
- (3) Experiment with different glass combinations
- (4) Link to macrolens manufacturers



**Figure 7:** Image spot plots for the Orthoscopic wide filed lens design (2) that allows field curvature



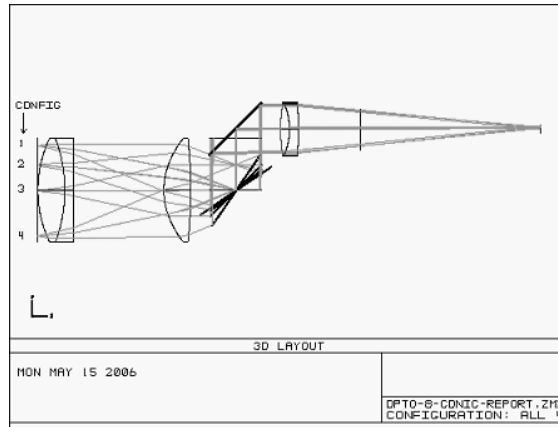
**Figure 8:** Fiber coupling performance of the Orthoscopic wide field eyepiece design (2)

### 3. POSM BEAM STEERING DEVICE

The POSM beam steering device is virtually independent from FLCG optical design. The mechanism is placed at the telescope pupil and steers the target beam into the optical fiber. Two beam steering mechanisms are currently being considered.

#### 3.1. Mirror (periscopic)

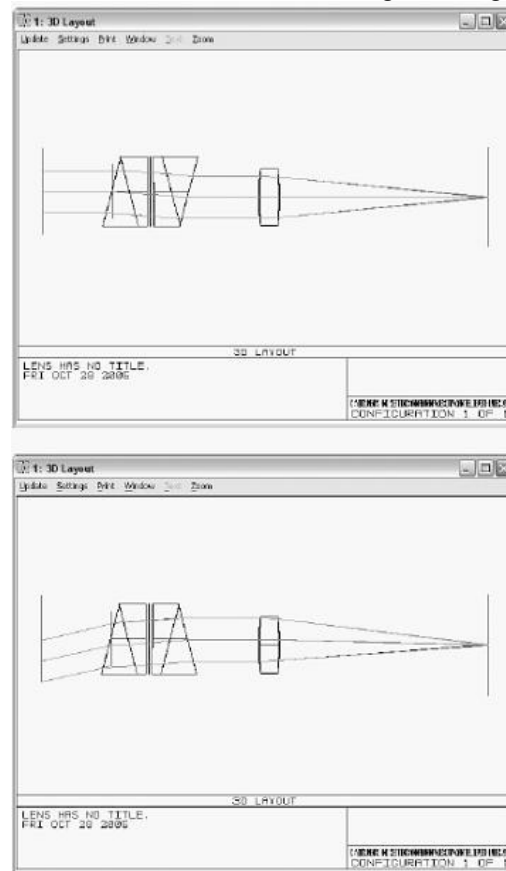
The periscopic beam steering device comprises two small mirrors one of which one is steerable. Shown in Figure 9 a steerable mirror is placed at the pupil position. This mirror is positioned in tip and tilt until the correct target beam is directed to the stationary mirror, and then to the optical fiber.



**Figure 9:** The periscopic beam steering device

### 3.2. Achromatic wedges (prismatic)

The prismatic beam steering device is an “Anti-” direct vision prism system for atmospheric dispersion correction. For the prismatic beam steering device we require maximum beam deviation without introducing significant dispersion. Figure 10 shows the relative rotation of the 2 cemented achromatic wedges for target selection.

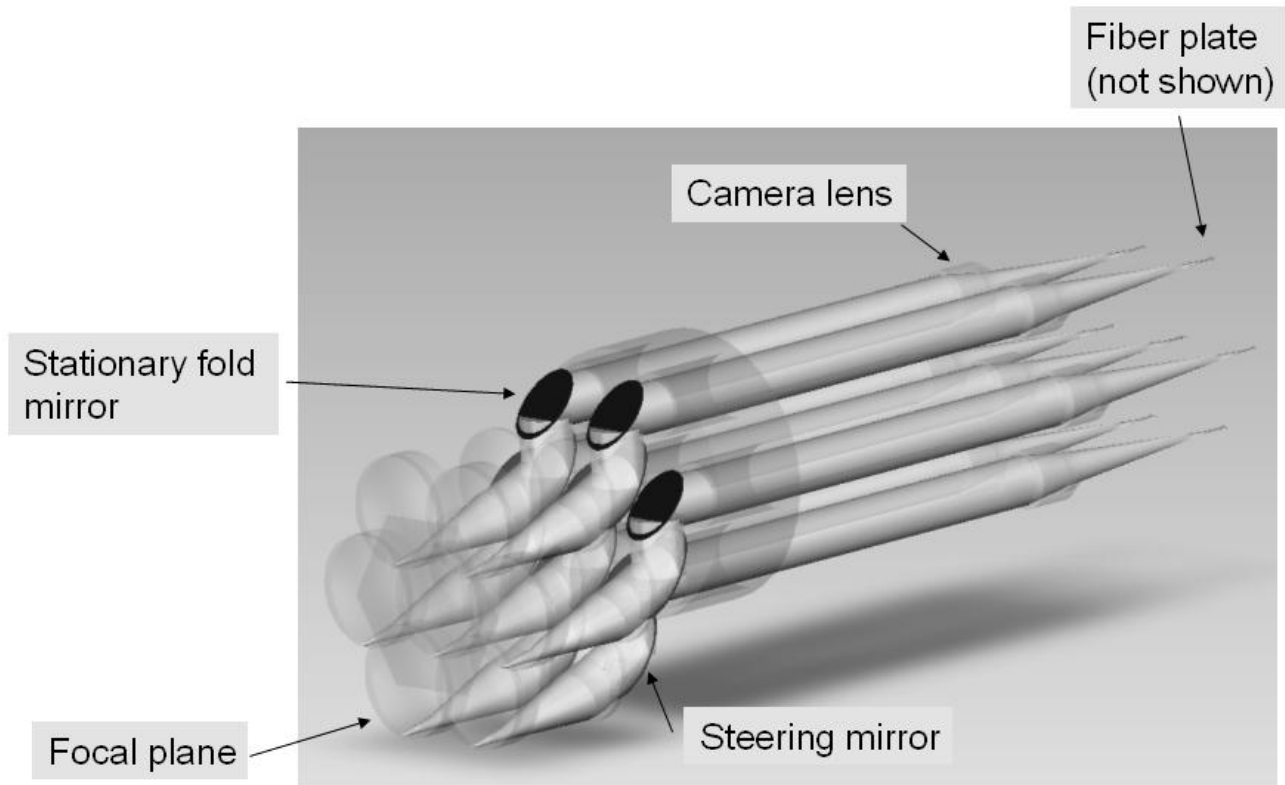


**Figure 10:** The use of achromatic wedges as the POSM beam steering device. The top figure depicts an on-axis target selection. By altering the rotation of the relative rotation angles of the achromatic wedges one can select an off-axis target (below).



#### 4. POSM MECHANICAL DESIGN

The mechanical design of the POSM positioner provides an interesting challenge with regards to packing and alignment in particular. A preliminary sketch of a periscopic layout of 7 channels is shown in Figure 11.



**Figure 11:**

##### 4.1. Mechanisms

The mechanism/s for the beam steering device must:

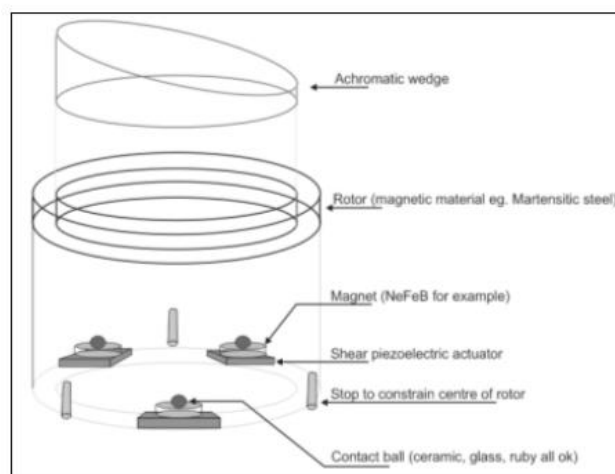
- Provide rotation (prismatic beam steering device) or provide tip/tilt (periscopic device)
- Have a clear aperture in the case of the prismatic solution
- Have sufficient positional resolution
- Have sufficient speed
- Have sufficient positioning accuracy

In the case of the prismatic beam steering device two mechanisms are being investigated. The first is based on the commercial UltraSonic Motor (USM) found in top of the range SLR cameras and shown in Figure 12. The second and likely preferred option from a complexity point of view is a shear motor design depicted schematically in Figure 13. The preferred mechanism currently for the periscopic device is a tip-tilt version of the shear motor described in Figure 13. All 3 mechanisms are to be prototyped.

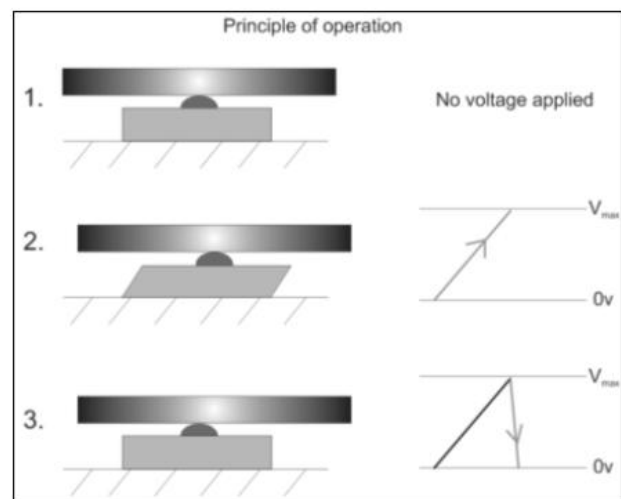


Ultrasonic motor by Canon Inc.

**Figure 12:** An Ultrasonic ring motor by Canon. This motor contains a piezoelectric stator (shown with grooves) and ceramic or metallic rotor. The drive signals are 2 acoustic waves that set up a standing wave in the piezoelectric crystal. This produces rotational movement of the rotor.



Schematic of motor



How it works

**Figure 13:** Schematic of a shear motor for rotation of the achromatic wedges. The motor is a type of stick-slip device, using the difference between static and kinetic friction to provide small rotational movements.

## 5. CONCLUSIONS

We present a new concept (POSM) for high multiplex fiber positioning where the optical fibers are fixed in position and an array of beam steering devices direct the target objects into the fibers. The science case must have high target densities compared to fiber density for efficient allocation (massive galaxy surveys, stellar surveys etc.). The single fiber plate is highly advantageous- the design is robust, easy to assemble, offers fast configurations and “dynamic” configurations. We intend to develop a smaller prototype for a Cassegrain or Nasmyth instrument as the POSM concept can accept any input f/ratio. POSM is in theory a very flexible concept – it can be located at any focus station.

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